PB-215 414

OXYGEN UPTAKE RATES OF BENTHAL DEPOSITS ON THE UPPER PASSIAC RIVER

O. M. Donovan, et al

Rutgers - The State University
New Brunswick, New Jersey

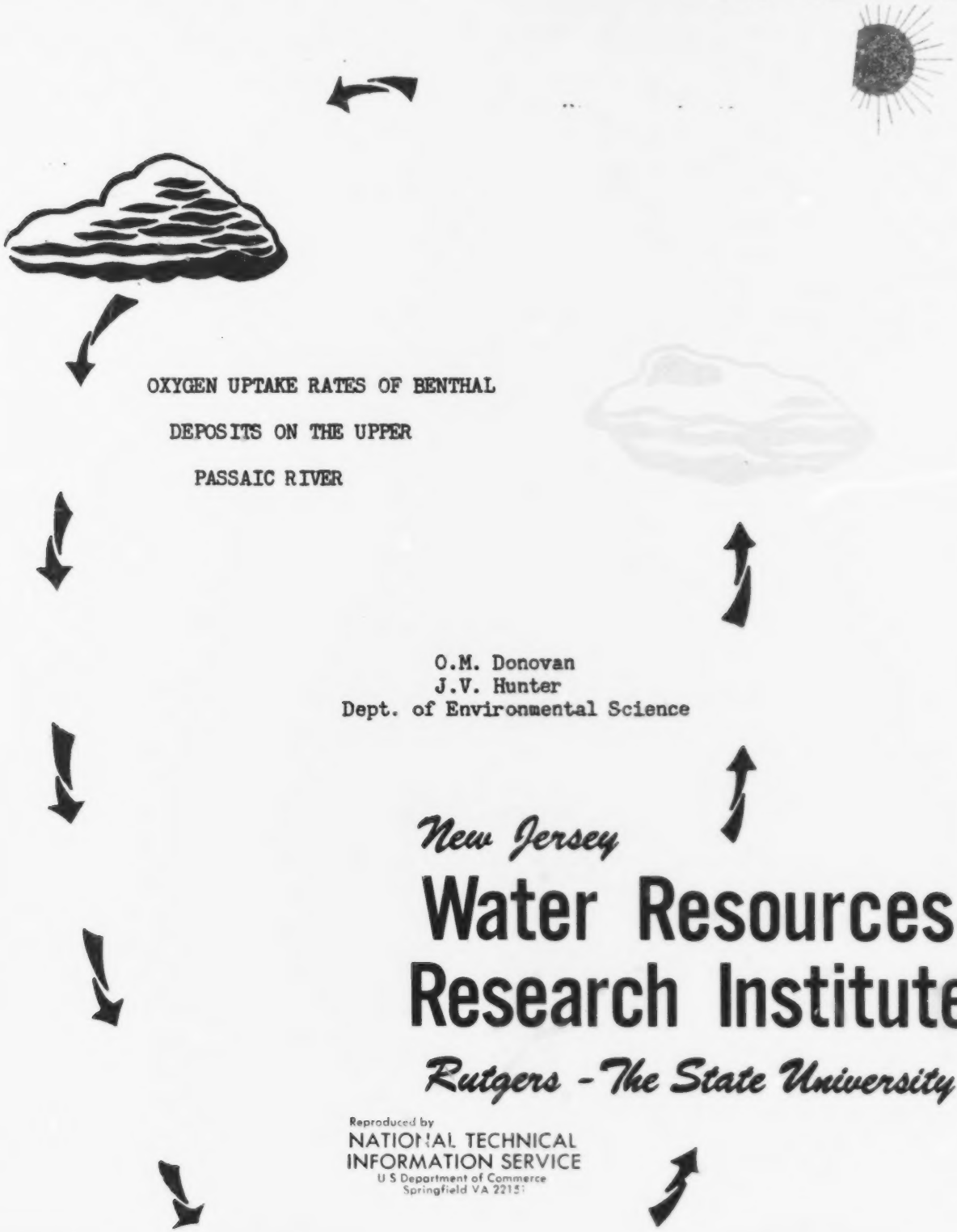
1969

DISTRIBUTED BY:

NTIS

National Technical Information Service
U. S. DEPARTMENT OF COMMERCE
5285 Port Royal Road, Springfield Va. 22151

PB 215 414



OXYGEN UPTAKE RATES OF BENTHAL DEPOSITS ON THE UPPER PASSAIC RIVER

O.M. Donovan
J.V. Hunter
Dept. of Environmental Science

New Jersey
Water Resources Research Institute
Rutgers - The State University

Reproduced by
NATIONAL TECHNICAL
INFORMATION SERVICE
U S Department of Commerce
Springfield VA 22151

Presented at the ASME/AIChE Water Pollution Conference, at Rutgers University, June 10 - 12, 1969. Research supported in part by a demonstration grant DUP 16080, Federal Water Pollution Control Administration.

OXYGEN UPTAKE RATES OF BENTHAL DEPOSITS ON THE UPPER PASSAIC RIVER

O. M. DONOVAN AND J. V. HUNTER

Abstract -- An in situ benthal respirometer was utilized to determine benthal oxygen demands on the Passaic river near Little Falls, New Jersey. Different deposits on the stream were examined. These exhibited demands ranging from 1.13 g/m^2-day to 3.79 g/m^2-day, with an average demand of 2.22 g/m^2-day. These demands were then examined from the viewpoint of their effects upon the overall stream oxygen balance. It was found that the benthic demand upon the supernatant water ranged from 0.261 mg/l-day at a flow rate of 200 cfs to 0.120 mg/l-day at flow rate of 1400 cfs. These data are presented in tabular and graphic forms in subsequent sections of this paper.

1) INTRODUCTION

Benthal deposits in a water body may have their origins in any one, or all, of a number of different sources. They may be due to the settling out on the stream bed of organic suspended solids present in the effluent stream of a domestic (or an industrial) waste treatment plant. They may also be due to the steady buildup of natural detritus on the stream bottom. This detritus might consist of such things as twigs, leaves, decaying attached plants, algae, and dead animal matter.

The fact that benthal deposits can have a pronounced effect on the oxygen balance of streams has long been recognized. This effect may well be a negligible one on broad, deep rivers where the volume of supernatant water passing over the deposit is great enough to render insignificant the oxygen demand of the benthos. In the case of a small, shallow river, however, the benthal demand may represent a significant oxygen sink on the supernatant water. This would be especially true where the stream velocity is not sufficient to prevent the deposition of organic particulates. Velz (1) has shown that water velocities less than 0.6 ft/sec will allow deposi-

Reproduced from best available copy.

tion of particulates, but that velocities greater than 1.0 ft/sec will cause erosion (scour of the stream bed.)

From Velz' work on deposition and scour velocities, it becomes evident that the hydrography of the stream plays the dominant role in determining whether or not a significant benthal deposit will be accumulated on the bed. For example, if a stream builds up a large benthal deposit as a result of lower winter stream velocities, it might be expected to scour its bed, at least partially, with the advent of higher velocities caused by the spring rains. In the case of large, sluggish rivers, scour velocities might never be reached, or reached only rarely. Significantly large benthal deposits can be expected to accumulate on such rivers. Similar deposits, for the same reasons, would be found behind dams and other impoundments.

River and other muds examined to the date of this writing vary widely in their abilities to utilize dissolved oxygen. Examination of table 2, this paper, will show that different deposits on the same stream differ markedly in this respect. As a general rule, benthal deposits which have originated as organic suspended solids from waste treatment facilities pose the greatest problem as far as detrimental effects on the oxygen balance is concerned. Muds from clear, unpolluted streams show a considerably lower rate of oxygen utilization than streams which act as receiving waters for domestic and industrial wastes.

Downing (2) points out that whereas respiration rates of muds from unpolluted reaches of stream are rarely greater than 1.2 g/m^2 day, those from polluted reaches can, and frequently do, attain much

higher values.

The highest respiration rate known to the writer was found by Owens and Edwards (3). They observed a rate of 22.0 g/m^2 day in benthal deposits on a river receiving only partially treated sewage. On this river, the benthal oxygen demand was so much in excess of the atmospheric reoxygenation rate that the dissolved oxygen in the supernatant water was quickly reduced to zero within a short distance of the effluent outfall. This is a classic example of the ability of potent benthal deposits to adversely affect the oxygen balance in streams.

As indicated by Fair et al (4) in a classic treatment of the subject, the decomposition of pollutional sediments proceeds in both an aerobic and an anaerobic phase. Aerobic conditions will prevail at and near the surface of the deposit, provided only that the supernatant waters contain dissolved oxygen. Oxygen will penetrate into the deposit, however, only so far as the limits of the balance between diffusion and oxygen consumption. At this point the anaerobic zone begins. As the deposit ages, products associated with anaerobic decomposition may be transported vertically upwards into the aerobic zone and its overlying waters where they, in their turn, will exert a further demand upon the oxygen resources of the stream. Pockets of gas formed by anaerobic digestion in the lower layers of the deposit will now and again break through the mud-water interface, exposing, as they rise, new surfaces susceptible to aerobic processes.

It will occasionally happen, in an unusually heavily polluted stream, that the respiration rate of the benthal deposits becomes

so great that the supernatant waters are completely deprived of dissolved oxygen. Anaerobic conditions will then provail throughout the entire vertical structure of the water body. A stream such as this, quite aside from its becoming a public nuisance (due to generation of products of anaerobic decomposition such as hydrogen sulphide), can also be called temporarily "dead."

In any theoretical discussion of the respiration rates of pollutional sediments, numerous factors should be considered. Among these are sludge age, depth, area, temperature, the nature of the deposit (whether natural or the result of waste treatment or industrial processes), and the physiochemistry of the water body under consideration.

Various authors (4) (5) (6) have reported high rates of oxygen demand while the deposit under study was relatively young. The respiration rates of the deposits during later stages of the trials showed a steady decrease. That these results are what one would expect can easily be shown by a consideration of the decomposition of organic matter by micro-organisms. The rate of decomposition in the deposit would depend jointly upon the amount of decomposable matter present and its availability to bacteria and other microbes. As the bacteria feed upon the organic matter, the total amount of this "food" would, of course, decrease with time. Also, the more available components of the substrate will be attacked first. The net result of the decrease in organic matter with time and the lessening availability of food substances is a deceleration of the respiration rate of the deposit as it ages.

The effects of sludge aging, although interesting from a theoretical point of view, are of little consequence in the consideration of

in-place benthal deposits in natural water bodies. This, of course, is due to the fact that, in practically all cases, new pollutional sediments are being continuously laid down.

Temperature plays an important role in the oxygen consumption rate of a benthal system. Hanes and Irvine (7) found a decreasing oxygen uptake rate with decreasing temperatures in older (stabilized) benthal deposits. In newer deposits, however, they found that the uptake rate decreases when temperature decreases from 25-20°C but not from 20-15°C. Other studies (8) (9) have demonstrated significant changes in rates of benthal respiration with seasonal changes in temperature. This might be one of the factors to be considered in any long term study on a natural benthal deposit.

Numerous investigations have been carried out on the effect of sludge depth on the respiration rate of benthal deposits. Early investigations by Baity (10) and Fair (4) seemed to indicate that the depth of the deposit played an important role in the oxygen uptake of a benthal system. More recent studies, however, such as that by Davison and Hanes (5), and Stein and Denison (11), indicate that the effect of sludge depth on oxygen uptake is negligible. As suggested by Davison and Hanes, correlations between sludge depth and oxygen uptake in the earlier studies were probably due to such phenomena as vertical transport of decomposition products during consolidation of the deposit and the constant disturbing of the sludge surface by pockets of gas formed in the process of anaerobic digestion. The literature to date clearly indicates that in any consideration of the depletion of stream oxygen resources by benthal deposits, the area of such deposits rather than their depth should be the prime factor considered.

Reproduced from best available copy.

Physical and chemical factors existing in a water body may also play a role in the depletion of dissolved oxygen by pollutional sediments. Among physical factors the most important is stream velocity. It has already been noted that low velocities will cause deposition, and that higher velocities will cause scour. Varying velocities within the same stream will cause a benthal deposit to be laid down in one place, while in another the stream bed is scoured clean. Correlations have been found between chemical parameters in bottom muds, such as that found by Edwards and Rolley (8) between permanganate value and organic carbon content, and that found by Lenhard et al (12) between Kjeldahl nitrogen and humic acid content. Rolley and Owens (13) attempted to correlate oxygen consumption of muds with various chemical parameters, but were unsuccessful in this. They did, however, demonstrate a remarkable correlation between humic acid and permanganate.

As pointed out by McKeown et al (6) chemical agents present in a waste effluent to a receiving body of water may act to precipitate dissolved solids, or to flocculate fine suspended solids which, under existing conditions of velocity, would not have been capable of settling out without this chemical action.

Various methods exist for determining the oxygen uptake rate of a benthal system. One of them, of course, is discussed in this paper. This concerns the in-place, on-stream determination of respiration rates utilizing portable equipment. Uptake rates may also be calculated for a given deposit after determination of such factors as 5 day, 20°C BOD in grams per kilogram of volatile matter. A potentially very useful expression in this regard is given by Fair and Geyer (14). The expression given is an approximate one, however, and appropriate care should be

taken with regard to its use.

Numerous workers have collected cores from deposits of pollutional sediments and analyzed them in the laboratory. Although much interesting and useful work has been accomplished by use of this method, it is felt by the writer that an in-situ respirometer, such as that used in this study, by Stein and Denison (11), and by O'Connell and Weeks (15), gives a much more accurate picture of oxygen uptake rates as they actually exist on the stream bed.

A question still remains to be answered in the literature as to whether or not the deposition of pollutional sediments is detrimental from a standpoint of the sanitary economy of a water body. Deposition of settleable material on the stream bed means that this material will probably not exert an immediate, heavy demand upon the dissolved oxygen in the supernatant water, but will sit in storage awaiting scour of the bed by spring freshets. As the literature indicates, the buildup of rather large depths of deposit, under small surface areas, will probably be of net benefit to the water body. If all this organic material had been oxidized within the supernatant water, the over-all effect on stream oxygen balance would, in all probability, have been much more severe. It should be kept in mind, however, that under conditions of uniformly low velocity, as behind an impoundment, pollutional sediments may cover such an extensive area that the dissolved oxygen in a considerable portion of the overlying water volume may be reduced essentially to zero.

Lastly, if prediction equations are to be used in engineering studies of the stream in question, it is necessary to quantify the benthal oxygen

demand. This point is illustrated by consideration of Camp's (17) version of the oxygen sag equation.

$$D_b = \frac{K_1}{K_2-K_1} L_a - \frac{p}{2.3K_1} 10^{-K_1 t} - 10^{-K_2 t} + \frac{K_1}{K_2} \frac{p}{2.3K_1} - \frac{}{2.3K_1} 1 - 10^{-K_2 t} + D_a 10^{-K_2 t}$$

where:

D_b = oxygen deficit ($C_s - C_b$) in mg/l at point b downstream, separated from point A by t days

C_s = saturation value of oxygen in mg/l

C_b = oxygen level at point b in mg/l

L_a = ultimate BOD at point a in mg/l

= oxygen added by photosynthesis in mg/l

p = oxygen removed by benthal deposits in mg/l

K_1 = deoxygenation constant

K_2 = reaeration constant

It may easily be seen here, that, along with stream BOD, the benthal demand forms a major sink of dissolved oxygen. All sinks and sources of oxygen must be quantified in order to effectively use the oxygen sag equation.

Reproduced from best available copy.

2) EQUIPMENT AND EXPERIMENTAL PROCEDURE

The principal items of equipment utilized in the study were as follows:

1) Delta Scientific Model 75 Oxygen Meter with Polarographic Probe
2) Probe housing, stirring motor, and battery
3) Lucite respirometer

The first step was the calibration of the oxygen meter, using the Winkler determination for dissolved oxygen as the primary standard.

Once a suitable benthal deposit had been located by probing of the stream bed, the oxygen probe and housing were inserted into the top of the respirometer. Respirometer and probe were then lowered onto the deposit. Care was taken to ensure a good seal between respirometer and mud.

Before each reading, the temperature of the water was noted and the meter adjusted accordingly. Initial and final readings were taken, and calculations performed to determine the uptake of the deposit in grams/m^2/day. The BOD of the water was taken for the exact time period that the uptake run was in progress. This was so that the BOD could be subtracted from the oxygen uptake in the final calculations.

Studies on the extent of the benthal deposits were carried out using a large length of calibrated line, a benthal probe, and a boat.

A diagram of the basic experimental set-up is found in figure 1.

3) RESULTS

The location of the sampling points along the stream and accompanying temperature data are found in Table 1. Uptakes of dissolved oxygen, along with calculated benthal demands are presented in Table 2. Daily uptake rates were determined by linear extrapolations of observed uptake data. A sample uptake curve is presented in Figure 2. Observations on the areal extent of the benthal deposits on that portion of the stream considered are found in Table 3.

The average benthal demand of those deposits considered in the study was found to be 2.22 grams/day/meter^2. A review of the literature (Section 1, this paper) shows that this is a rather typical value, neither particularly high nor low.

Areal studies showed that the average linear distance across the stream was 74.63 ft. The average linear distance across the stream covered by mud was found to be 16.45 ft. These data indicated that roughly 22% of the stream bottom along the reach studied was covered by benthal deposits of various depths.

Certain difficulty is encountered in extrapolating the results of the areal and benthal demand studies in order to predict the average benthic demand upon the supernatant water as a function of stream flow.

First, the assumption is made that the bottom is uniform in average mud coverage and demand along the length of the stream. Taking a typical square meter of bottom surface, therefore, it would be 22% mud and would exert 22% of the average benthal demand. This is 0.4886 gr/day-m^2.

If the stream bed is constant with distance, then a segment of water moving downstream for a day would have the same benthic demand placed on it as if it had remained in place. Thus, the only influence that an in-

creasing Q (discharge rate) would have would be to increase both the depth of water over the deposit and the dilution of the benthic demand. This effect was calculated and is presented in Figure 3.

Benthic demand in terms of gm/m^3(mg/l)/day was calculated for a discharge rate of 200 cfs as follows:

gm/m^2-day x m2 of deposit = gm/day = total uptake over deposit

$$\frac{gm/day}{\text{volume over deposit } (m^3)} = gm/m^3 \text{ (mg/l)/day}$$

This initial demand was then reduced for increasing flow rates simply by multiplying by the ratio of the mean stream depths at these flow rates, as:

gm/m^3(mg/l)/day (200 cfs) x d (200 cfs)/ d (subsequent cfs) = gm/m^3(mg/l)/day at subsequent cfs

The results of these calculations were checked by considerations of increasing deposit area with flow, where the demand of the added areas remained at 0.4886 gm/m^2 day. The two methods coincided almost exactly.

Benthic demands upon the supernatant water ranged from 0.261 gm/m^3(mg/l)/day at a discharge rate of 200 cfs to 0.120 gm/m^3(mg/l)/day at a discharge rate of 1400 cfs.

Solids determinations and BODs were done on a sample sediment from one location for characterization purposes. Dry solids, as % of wet sediment by weight, was found to be 27.16%. Volatile solids, as % of dry solids by weight, was found to be 16.15%.

Suspensions of the sediment were prepared, at different dilutions, in BOD bottles and incubated for five days at 20°C. This was done in an effort to gain some insight as to the potentiality of the deposit

in causing stream damage if the sediments were somehow to be suddenly suspended in the bulk of the stream.

The average demand of the suspended sediments was found to be 121 grams of oxygen per kilogram of volatile matter (121 gm/kg). By the depth of sediment (.457m) under the respirometer at the sample collection point, it was possible to calculate the volume of pollutional sediment directly underneath one m2 of surface. This volume was $.457m^3$. From the solids determinations it was a simple matter to calculate the weight of volatile solids contained in this volume of sediment. This weight was 22.8 kg of volatile matter.

Since the 5 day, 20°C BOD suspensions had shown an average oxygen uptake of 121 gm/kg vol. matter, the oxygen depletion which would be caused in the stream by the suspension of 22.8 kg of volatile matter was easily visualized. The suspension of this amount of volatile matter would cause a loss to the supernatant water of 2760 grams of oxygen.

4) DISCUSSION

Studies done on the upper Passaic river in the summer of 1963 showed that the benthal deposits present had an average oxygen demand of 2.22 gm/m^2-day. This is a rather typical result for this type of study, being neither particularly high nor low. It does, however, point up the fact that the reach of the stream studied is a polluted one, since unpolluted streams rarely show benthal oxygen demands greater than 1.0 gm/m^2-day. Further, it should be kept in mind that this figure represents an average value. Individual deposits on the stream showed both higher and lower results. The highest benthal demand observed was 3.79 gm/m^2-day. This result falls within the higher range of values reported by the literature and may be regarded as being indicative of severe pollution.

As a general rule, the higher demands observed were found to occur where the river, for reasons of stream geometry, lost velocity. For example, at the point where the stream widened to its maximum extent, and consequently underwent its greatest loss in velocity, the highest demand was noted. It is suggested that this phenomenon may be due to the fact that smaller organic particulates tend to settle out at lower values of stream velocity. It was also noticed that the lower values of benthal demand observed occurred in locations where the stream narrowed and velocity increased. Benthal deposits at such locations seemed heavily laden with inorganic particulates, as one might expect.

Areal studies carried out on the reach studied indicated that roughly 22% of the river bed was covered with pollutional sediment. From this information, along with the respirometer runs, benthal oxygen demand was ca-

lated as a function of discharge rate. It was found that the benthic demand upon the supernatant water ranged from 0.261 gm/m^3(mg/l)day at a discharge rate of 200 cfs to 0.120 gm/m^3(mg/l)day at a flow rate of 1400 cfs.

Although these demands are significant in themselves, they are not so great when compared to the BOD taking place in the bulk of the stream. Table 4 shows the results of BOD studies done on the stream during the same time period that the benthal work was in progress. The average BOD was found to be 9.04 mg/l and the average coefficient of removal was found to be .345 day^{-1}. The removal coefficient (k_1) was calculated using the method proposed by Rhame (16). Another way to express these results would be to say that 34.5% of the average BOD of 9.04 mg/l, or 3.12 mg/l, would be exerted per day. It may easily be seen that daily oxygen depletion due to stream BOD is considerably higher than even the largest benthal demand expected at the lowest flow.

A glance at figure 3, where 5 day 20°C BOD, 1 day 20°C BOD, and daily benthal demand are plotted versus discharge rate, will further illustrate the large gap between benthal demand and BOD. It may be concluded from these data that, at least on the Passaic River, the BOD constitutes a much more significant sink of dissolved oxygen than does the benthal demand. It should be kept in mind, however, that this may not be the case on every stream considered. Situations have been known to occur (3) in which the benthal demand formed the major sink of dissolved oxygen on the stream.

If the average 1 day, 20°C BOD were produced by a single source of pollution, it would be reduced in successive intervals of travel time

by a factor of 34.5% per day (K_1). This effect was calculated and is presented in figure 4 along with the daily benthal demand at 200 cfs. It is assumed here, of course, that the benthal demand remains constant along the length of the stream. Near the point of discharge, it may be seen that the BOD is the predominant sink of dissolved oxygen. As self-purification processes proceed in time, however, the BOD approaches, and then becomes less than the benthal demand. Unfortunately, this is a purely hypothetical situation which could only be observed on a stream with a single source of pollution. On the Passaic, the BOD stays relatively constant with time due to the multiplicity of pollutional sources.

In order to gain insight into the potential of the deposits in causing stream damage, if suddenly suspended in the bulk of the stream, solids and 5 day, 20°C BOD bottle suspension studies were done in the laboratory. The average demand of the suspended sediments was found to be 121 grams of oxygen per kilogram of volatile matter. It was then calculated that if the entire volume of sediment under 1 or 2 of mud surface in the region of highest demand, were suddenly loosed into the supernatant water, a total loss to the stream of 2760 gm (2.76×10^6 mg) of oxygen would occur. A short mental extrapolation of this figure to include the entire bulk of the pollutional sediments on the upper Passaic River will demonstrate the enormous potential of these sediments in causing stream damage.

5) SUMMARY

1) The average benthal demand observed on the upper Passaic River was 2.22 gm/m^2-d.

2) The greatest benthal demand observed was 3.79 gm/m^2-d. This is indicative of severe organic pollution.

3) Benthic demand upon the supernatant water ranged from 0.261 gm/m^3(mg/l)/day at a discharge rate of 200 cfs to 0.120 gm/m^3(mg/l)/day at a discharge rate of 1400 cfs.

4) Figure 3 shows that, on the upper Passaic, stream BOD constitutes a much more appreciable sink of dissolved oxygen than does the benthos. This is no reflection on the strength of the deposits, however, but is mainly due to the fact that they cover only 22% of the stream bed.

TABLE I

Location of the Sample Sites

Run	Date	Distance from Aerator (ft.)	Temperature °C Initial	Final
1	7/20/68	1,100	24.0	22.3
2	7/29/68	3,000	22.4	24.5
3	8/5/68	7,000	23.4	24.3
4	8/14/68	13,000	21.5	22.1
5	8/16/68	14,000	21.0	21.8
6	8/20/68	15,000	21.6	22.6
7	8/22/68	3,300	22.8	23.7
8	8/28/68	4,000	22.1	23.8
9	9/3/68	6,500	20.2	23.9
10	9/5/68	8,250	21.0	21.7

TABLE II

Benthic Oxygen Demand as Calculated from Respirometer DO Values and BOD

(A) Run #	(B) D.O. initial mg/l	(C) D.O. Final mg/l	(D) time hrs	(E) time days	(F) BOD mg/l	(G) B - C	(H) G - F	(I) H x 28	(J) I/E x 0.0994 mg/d/m^2
1 *	6.0	2.35	15	0.625	2.34	3.63	1.31	36.7	--
2	3.0	0.30	5.5	0.229	0.70	2.70	2.00	56.0	2460
3 *	1.78	0.78	3.25	0.136	0.50	1.00	0.50	14.0	--
4	1.95	0.50	2	0.083	0.60	1.45	0.85	23.8	2870
5	1.50	0.05	2	0.083	1.00	1.45	0.45	12.6	1520
6	2.85	1.05	3	0.125	1.30	1.80	0.50	14.0	1130
7	1.40	0.30	1.5	0.063	0.40	1.10	0.70	19.7	3180
8	4.30	1.00	5.	0.208	0.50	3.30	2.80	78.5	3790
9	2.90	1.50	4.23	0.177	0.55	1.40	0.85	23.8	1354
10	1.15	0.25	3	0.125	0.25	0.90	0.65	18.2	1470

* A good seal was not achieved between respirometer and mud.

TABLE III

Extent of Benthal Deposits

Distance from Aerator (ft.)	Distance Across Stream (ft.)	Distance covered by Mud (ft.)
500	74	30
1,000	75	13
1,500	73	0
2,000	80	0
2,500	60	10
3,000	80	17
3,500	120	120
4,000	75	25
4,500	62	12
5,000	45	0
5,500	70	10
6,000	60	0
6,500	53	3
7,000	80	20
7,500	53	3
8,000	70	14
8,500	48	8
9,000	85	17
9,500	86	26
10,000	60	8
10,500	73	10
11,000	66	22
11,500	70	22
12,000	81	28
12,500	84	6
13,000	75	3
13,500	90	15
14,000	108	15
14,500	92	18
15,000	85	15
15,500	75	22
16,000	80	15
	Avg. = 74.63	Avg. = 16.45

Fraction = 0.22

TABLE IV

L_o and k_1 Values for the Passaic River *

Sample Type	Identification Date	k_1 $days^{-1}$	L_o mg/l
Composite	7/26/68	0.114	9.2
Composite	8/8/68	0.187	7.8
Composite	8/12/68	0.088	16.9
Composite	8/19/68	0.250	7.4
Composite	8/22/68	0.114	9.2
Composite	8/27/68	0.127	12.9
Composite	9/26/68	0.117	6.8
Grab 9:15 a.m.	9/4/68	0.109	6.9
Grab 3:15 p.m.	9/4/68	0.126	6.1
Grab 9:15 p.m.	9/4/68	0.186	7.7
Grab 3:15 a.m.	9/5/68	0.195	9.0
Grab 9:15 a.m.	9/5/68	0.196	8.5

TABLE V

Variations in BOD with Discharge Rate

Discharge Rate (cfs)	5 Day 20°C BOD (mg/l)	1 Day 20°C BOD (mg/l)
125	7.2	2.50
105	7.3	2.54
89	11.4	3.97
111	7.3	2.54
110	10.6	3.68
148	5.9	2.06
125	8.3	2.89
101	8.7	3.03
223	7.2	2.50
940	3.9	1.36
904	5.1	1.77
925	3.6	1.25
910	3.3	1.15
540	4.5	1.57
510	6.3	2.19
128	8.1	2.82
98	6.7	2.33
110	7.9	2.75
103	9.5	3.30

FIGURE 1

A SIMPLE SCHEMATIC FOR BENTHAL RESPIROMETRY

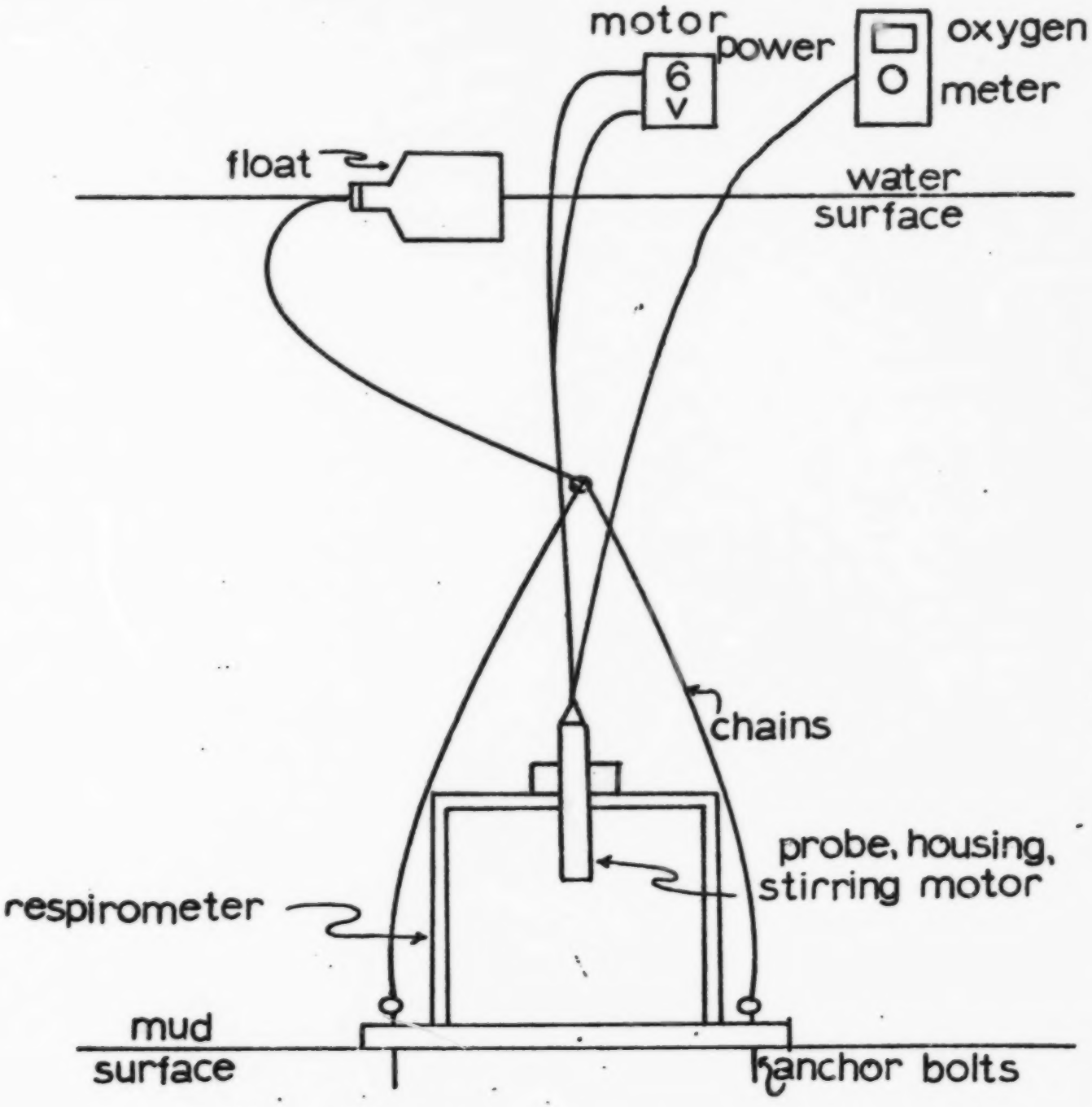


FIGURE 2 RESPIROMETER D.O. VS. TIME

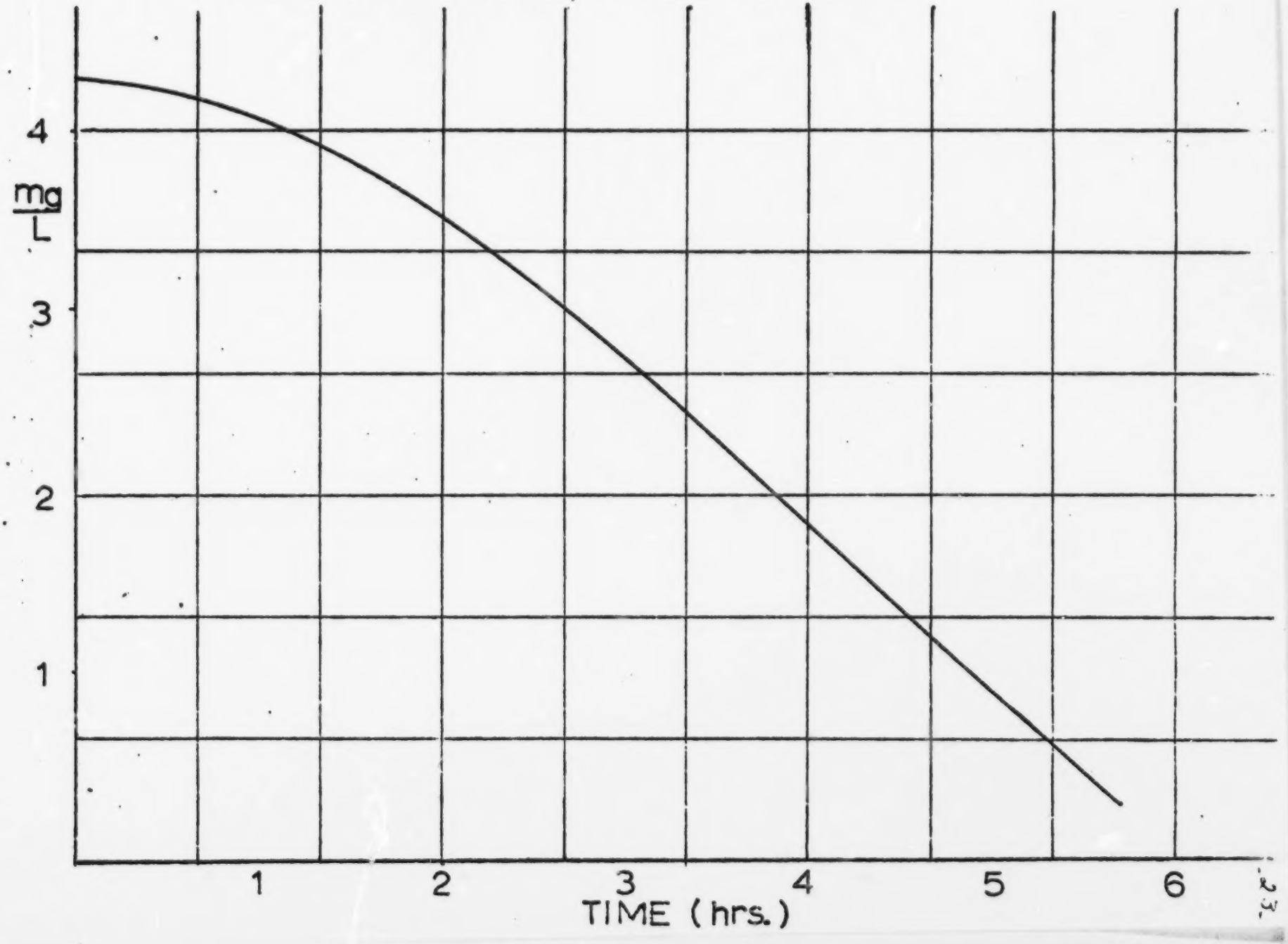
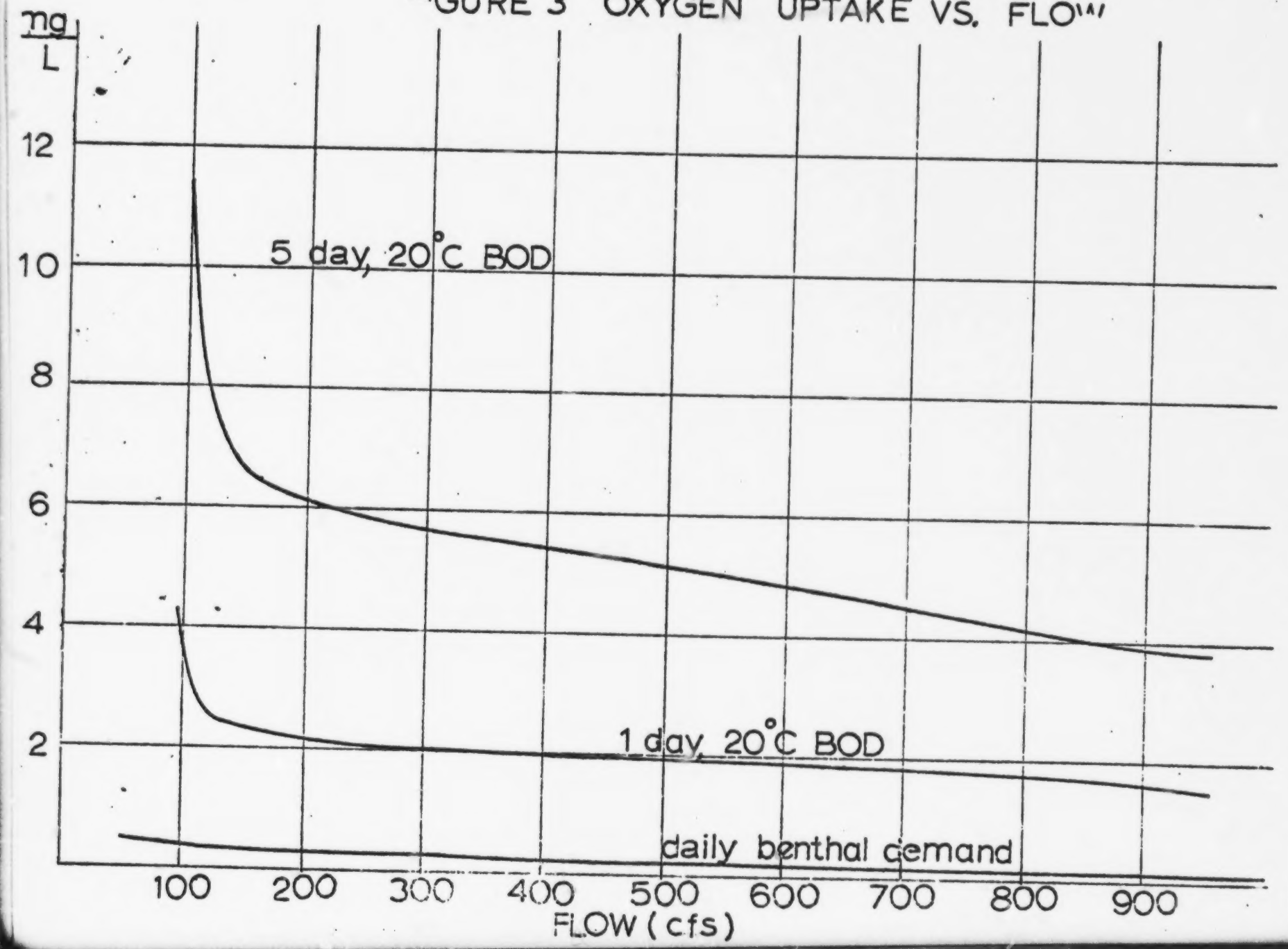


FIGURE 3 OXYGEN UPTAKE VS. FLOW



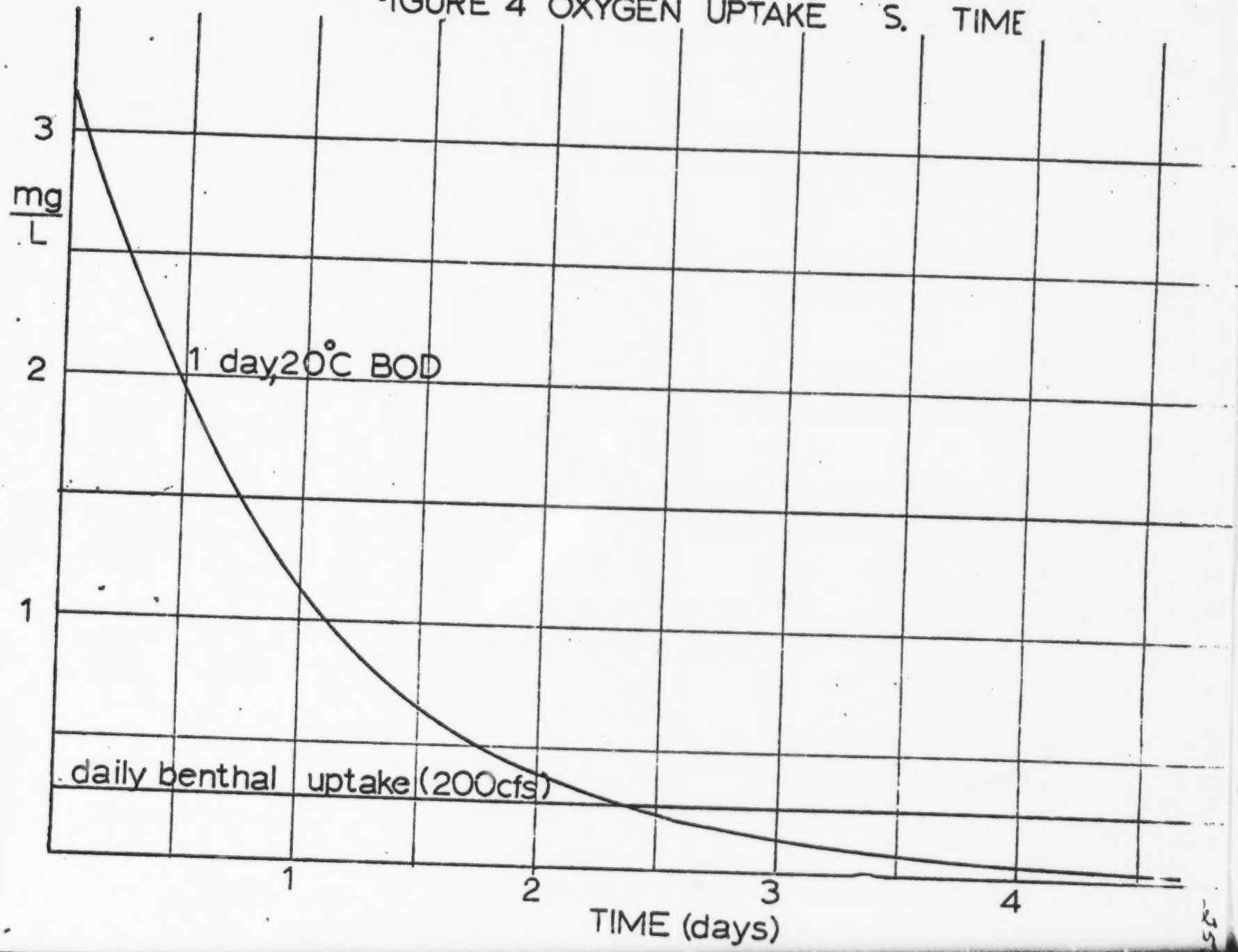


FIGURE 4 OXYGEN UPTAKE S. TIME
3
mg/L
2
1
1 day, 20°C BOD
daily benthal uptake (200cfs)
1
2
3
4
TIME (days)

REFERENCES

(1) Velz, C. J., "Oxygen Relationships in Streams," U.S.P.H.S., Robert A. Taft Sanitary Engineering Center, Tech. Rep. W58-2, pg. 47 (1958)

(2) Downing, A. L., The Effects of Pollution on the Oxygen Balance of Rivers, Water Pollution Research Laboratory, Stevenage, England, Reprint #517.

(3) Owens, M., and Edwards, R. W., Some Oxygen Studies in the River Lark, Proc. Soc. Wat. Treat. Exam., 12,126 (1963).

(4) Fair, G. M., Moore, E. W., and Thomas, H. A., The Natural Purification of River Muds & Pollutional Sediments, Sew. Works Journal, 13, (4) 756, (1941).

(5) Davison, R. L., and Hanes, N. B., Effect of Sludge Depth on the Oxygen Uptake of a Benthal System, Proc. of the 23rd Industrial Waste Conf., Purdue Univ. (1968).

(6) McKeown, J. J., Benedict, A. H., and Locke, G. M., Studies on the Behavior of Benthal Deposits of Papermill Origin, National Council of The Paper Ind. for Air and Stream Improvement, Inc., 103 Park Avenue, New York, N. Y., Technical Bulletin No. 219, September, 1968.

(7) Hanes, N. B., and Irvine, R. L., New Technique for Measuring Oxygen Uptake Rates of Benthal Systems, Proc. of the 21st Industrial Waste Conference, Purdue Univ. (1966).

(8) Edwards, R. W., and Rolley, H. L. J., Oxygen Consumption of River Muds, Jour. Ecol., 53,1 (1965).

(9) Mohlmann, F. W., Oxygen Demand of Sludge Deposits, Sew. Works Jour., 10,3,613 (1938).

(10) Baity, H. G., Some Factors Affecting the Aerobic Decomposition of Sewage Sludge Deposits, Sew. Works Jour., 10,539 (1938).

(11) Stein, J. E., Denison, J. G., In Situ Benthal Oxygen Demand of Cellulosic Fibers, Proc. Third International Conf. on Water Pollution Research, Munich, Germany, (1966).

(12) Lenhard, G., Ross, W. R., and Du Plooy, A., A Study of Methods for the Classification of Bottom Sediments of Natural Waters, Hydrobiologia, 20,223-240 (1962).

(13) Rolley, H. L. J., and Owens, M., Oxygen Consumption Rates and Some Chemical Properties of River Muds, Water Pollution Research Laboratory, Stevenage, England, Reprint No. 530.

(14) Fair, G. M., and Geyer, J. C., Elements of Water Supply and Waste-Water Disposal, John Wiley & Sons Inc., New York, (1965) 513-515.

(15) O'Connell, Weeks, An In-Situ Benthic Respirometer, FWPCA, CB-SRBP Technical Paper No. 6 (1965).

(16) Rhame, G. A., A Two-Point Method for Estimation of First-Stage BOD, Sewage and Industrial Wastes, 28, 1087 (1956).

(17) Camp, T. R., Field Estimations of Oxygen Balance Parameters for Polluted Streams, Sanitary Engineering Division, A.S.C.E., July, 1965.